DoE Award No. DE-FE31819

Additively Manufactured Graded Composite Transition Joints (AM-GCTJ) for Dissimilar Metal Weldments in Advanced Ultra-Supercritical Power Plant

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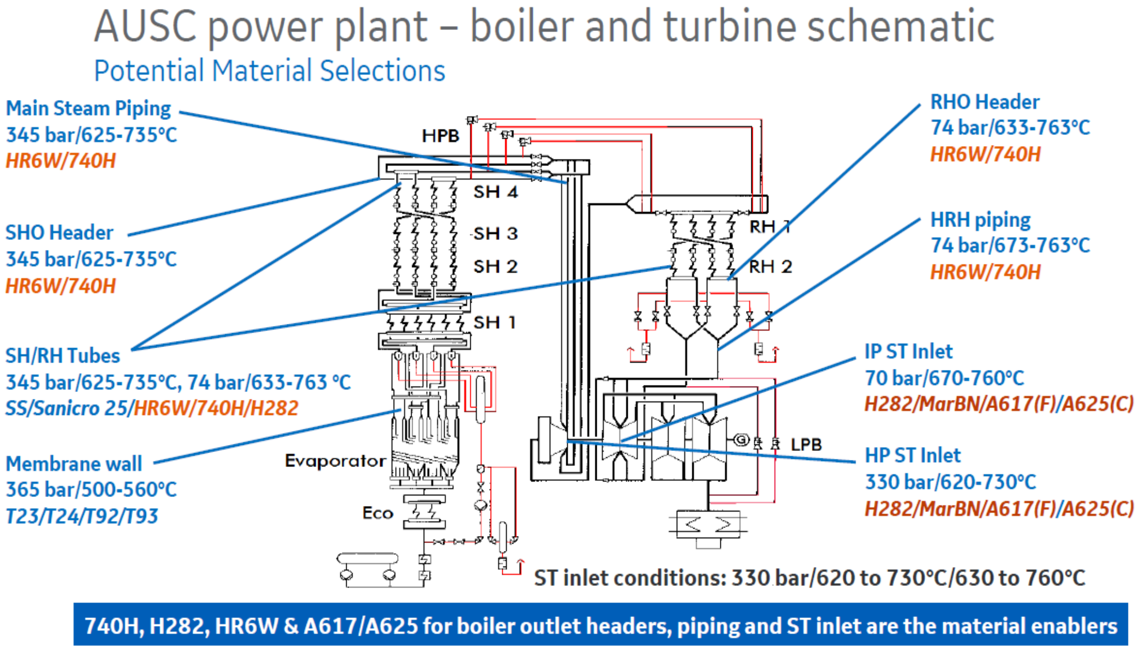
OUTLINE

- Background & Approaches
- Project Objectives
- Progress
- Summary & Future Work

DMWs in A-USC and HRSG



GE Steam: A-USC Mock Header

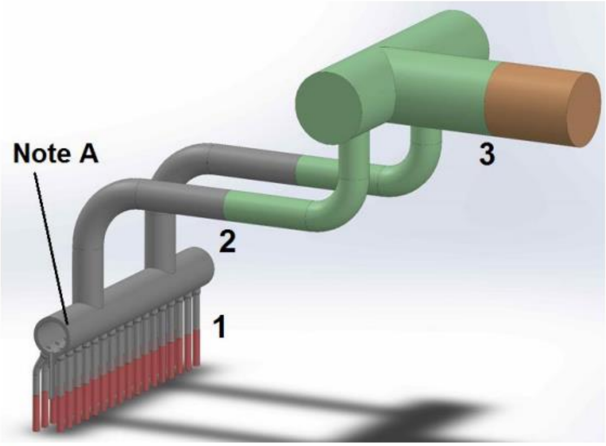


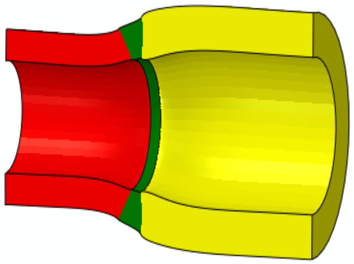
Figure 3-1
HRSG configuration highlighting potential DMW locations (1: tubing internal to the HRSG setting; 2: link piping; 3: outlet piping.)

Program on Technology Innovation: Guidelines and Specifications for High Reliability Fossil Power Plants—Best Practice Guideline for Manufacturing and Construction of Grade 91 Steel to Austenitic Stainless Steel Dissimilar Metal Welds 3002007221 Final Report, December 2017

DMW:

1. Grade 91 – Austenitic Stainless Steel
2. Ni based alloy – Austenitic Stainless Steel

Mismatch of coefficient of thermal expansion and **thermal cycling:**



DMW with sharp material transition

- Mismatch of coefficient of thermal expansion between different materials lead to high strain range along the interface during thermal transients.
- Increasing demand in industry for flexible operation of steam boilers and more cycling capability of HRSGs.

Higher cycling requirements in power industry:

- Steam Boilers: A sample required number of cycles for a new unit

	Total # of cycles of 25 years
Cold Start	455
Warm Start	910
Hot Start	4550

- HRSGs: Typical required number of cycles for a cyclic operating CCPP

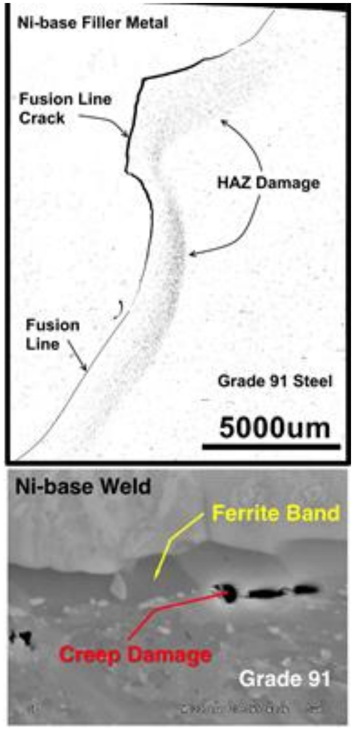
	Total # of cycles of 25 years
Cold Start	250
Warm Start	1250
Hot Start	4250

Current Dissimilar Metal Welds (DMWs)

Failures in DMWs @ the fusion boundary between Grade 91 and nickel based filler metal, often accompanied with considerable damages in the HAZ of Grade 91

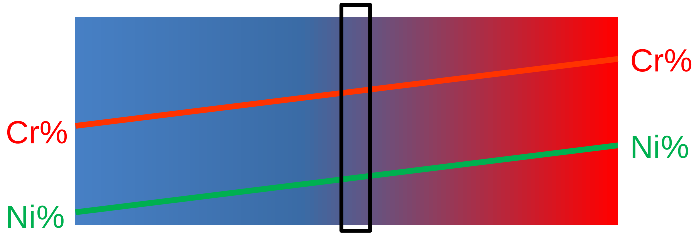
HT exposure during PWHT or service causes carbon diffusion from the ferritic matrix toward the austenitic matrix. Leads to the formation of a carbon-depleted soft zone on the ferritic side and nucleation/growth of carbides on the ASS side that have very high hardness.

Under imposed residual, external, and thermal stresses caused by the CTE mismatch between different alloys of the DMW, creep and/or creep fatigue cracks can occur along the fusion boundary and HAZ.



AM-Graded Transition Joints (GTJs)

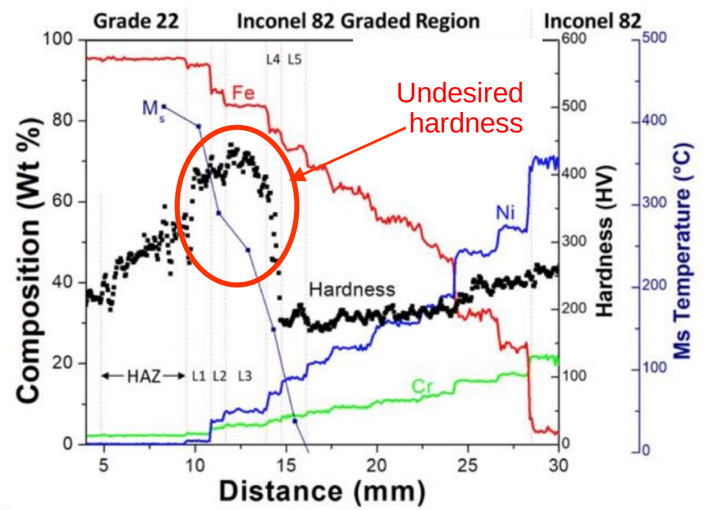
"Conventional" melting based AM



Grade 91
0.08C-9Cr-1Mo-0.4Ni

0.08C-14Cr-4Ni-0.5Mo:
microstructure?

SS304
0.08C-18Cr-8Ni



b) From: DuPont, Babu, Feng, 2018

- "Conventional" AM (wire or powder) approach melts alloys A&B completely together
  - A number of studies in the past (ORNL, Lehigh, UTK, Penn State etc.)
  - A critical issue is the continuous transition in composition creates complex and often undesired microstructure

Advantages of AM-GCTJ

- Solid-state Process, composites material" transition with constituents of known chemistry (such as P91, SS304, A182) mixed in controlled proportion
    - •Solved the critical drawbacks of undesired/unpredictable phases/microstructure in conventional AM approach to fabricate the transition joint
- 100% smooth transitions
- Welding happens at A-A, and B-B, no DMWs
- Minimize scale-up issues expected to manufacture large quantity of joints

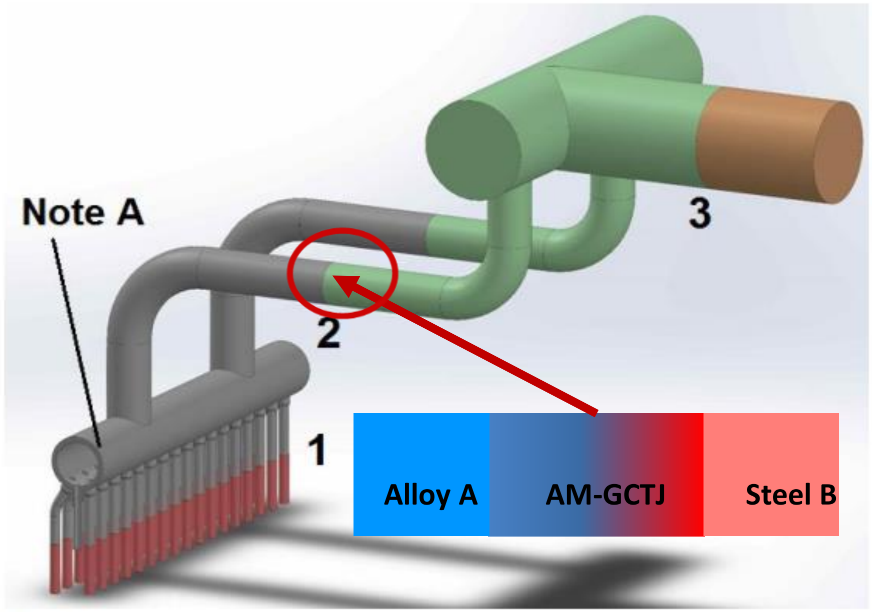


Figure 3-1
HRSG configuration highlighting potential DMW locations (1: tubing internal to the HRSG setting; 2: link piping; 3: outlet piping.)

Illustration of DM weld in fossil power plants

* U.S. Patent Appl. No. 62/704,965 – Method to Produce an Additively Manufactured-Graded Composite Transition Joint

PROJECT OBJECTIVES – PHASE I

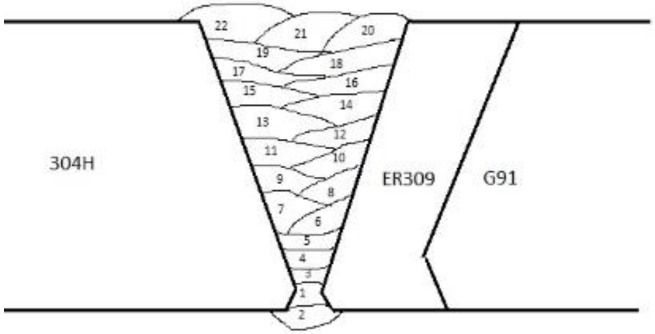
(1) To develop and demonstrate at the lab-scale the additively manufactured graded composite transition joints (AM-GCTJ) for dissimilar metal weldments (DMW) in next generation advanced ultra-supercritical (A-USC) coal-fired power plants, that can significantly improve the microstructural stability, creep and thermal-mechanical fatigue resistance, as compared with their conventional counterparts;

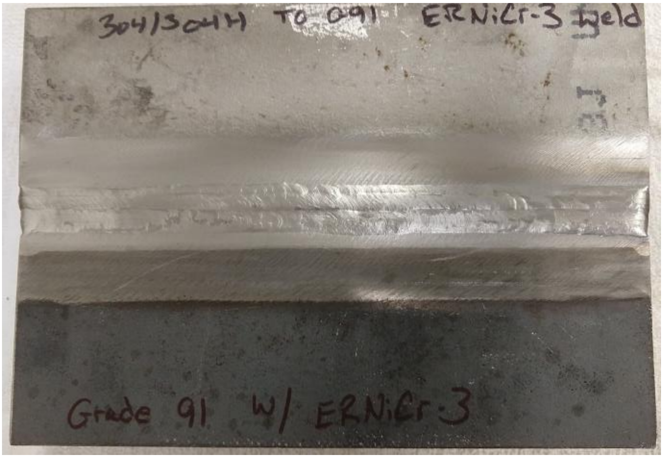
(2) To prepare for Phase II of the project, in which we will manufacture and test the components with AM-GCTJ, to advance the technology readiness level to TRL-7, and manufacturing readiness level to MRL 6-7, for targeted commercial applications identified by GE Steam Power, the primary industry partner of the project team

DMW and AM-GCTJ

AM-GCTJ

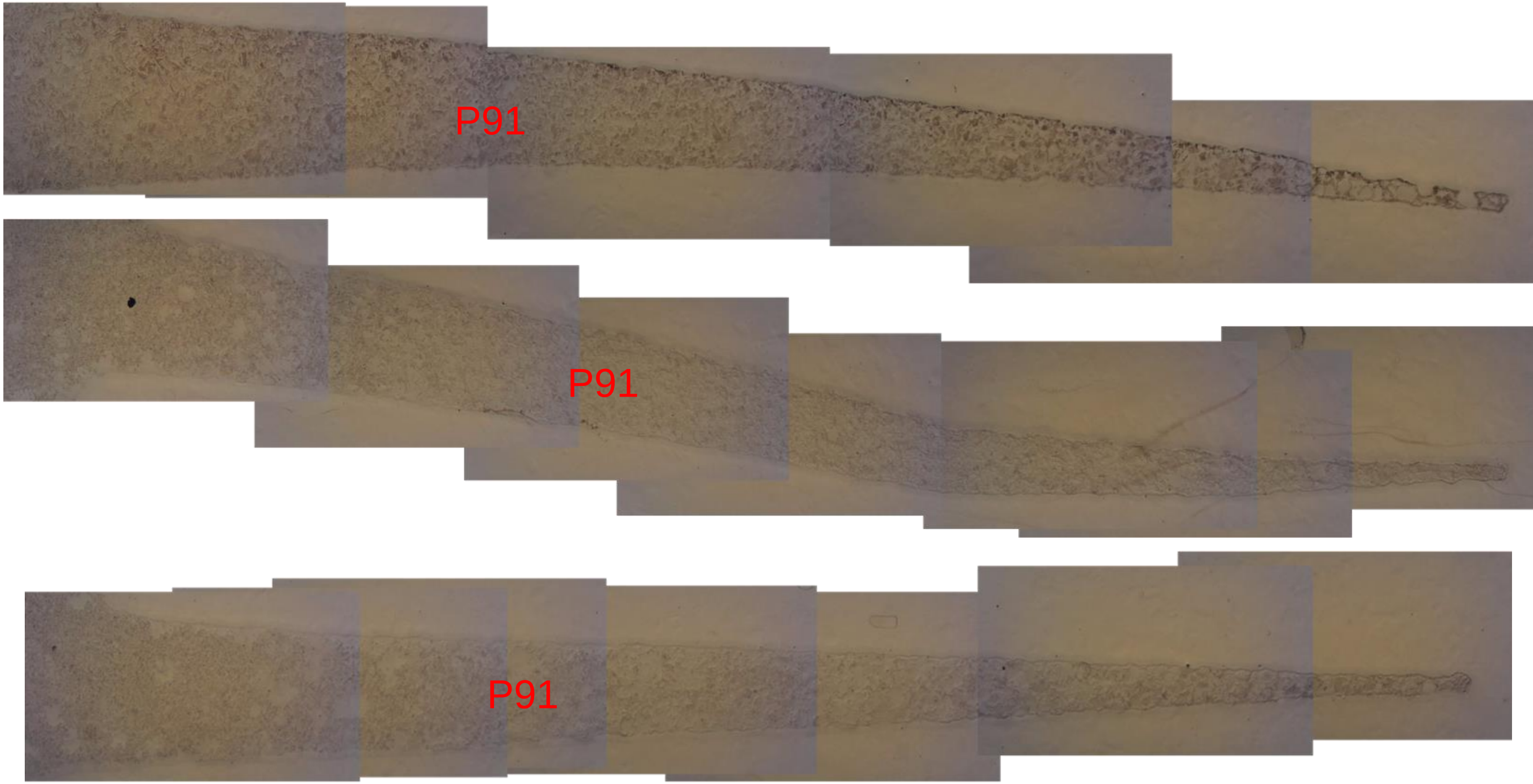
Conventional DM Weld





Fabricated 2 types of welds using either SS309 or A182 weld wire

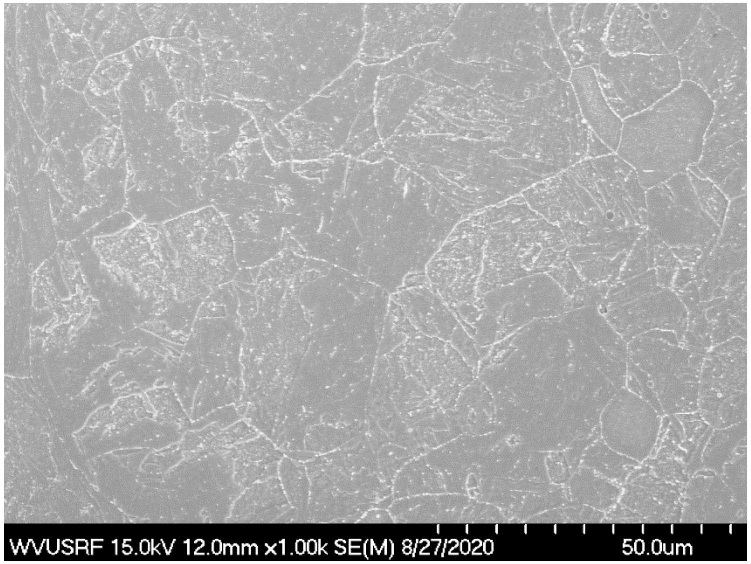
Microstructures of AM-GCTJ

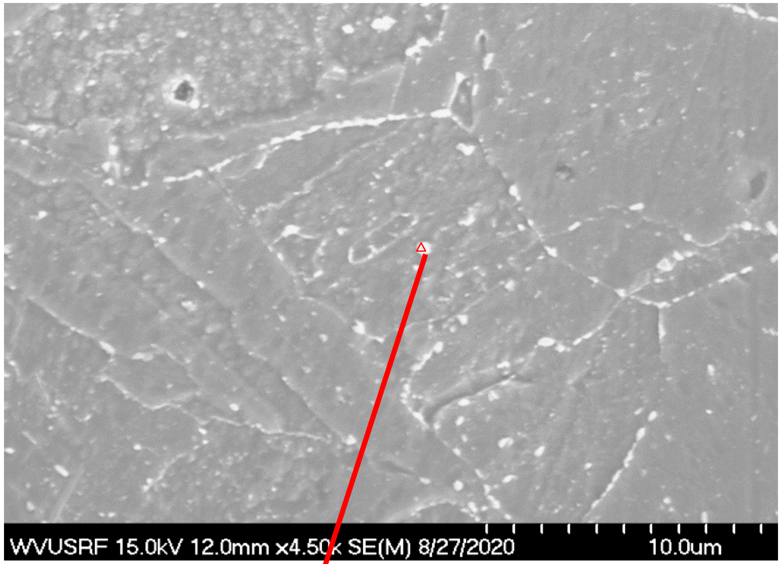


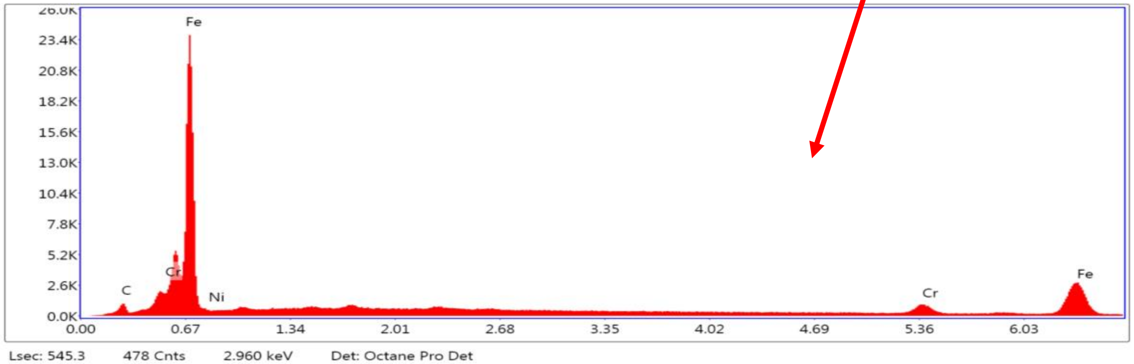
- ➢ No visible defects or microcracks were observed for the as-received 304H & P91 joints

Microstructures of AM-GCTJ

- P91 is composed of tempered sorbite (ferritic and carbides) and some prior austenite grain boundaries



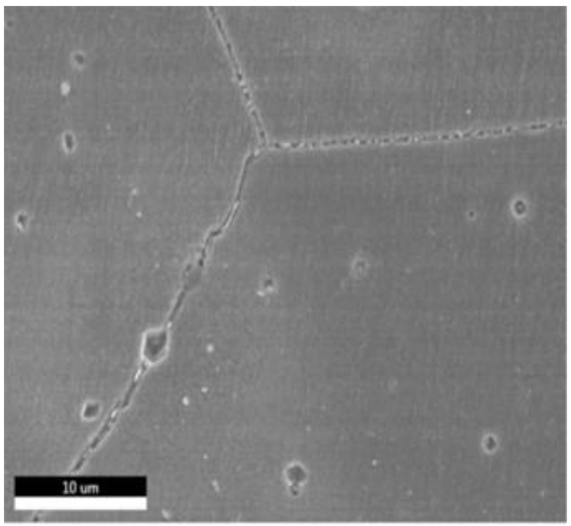


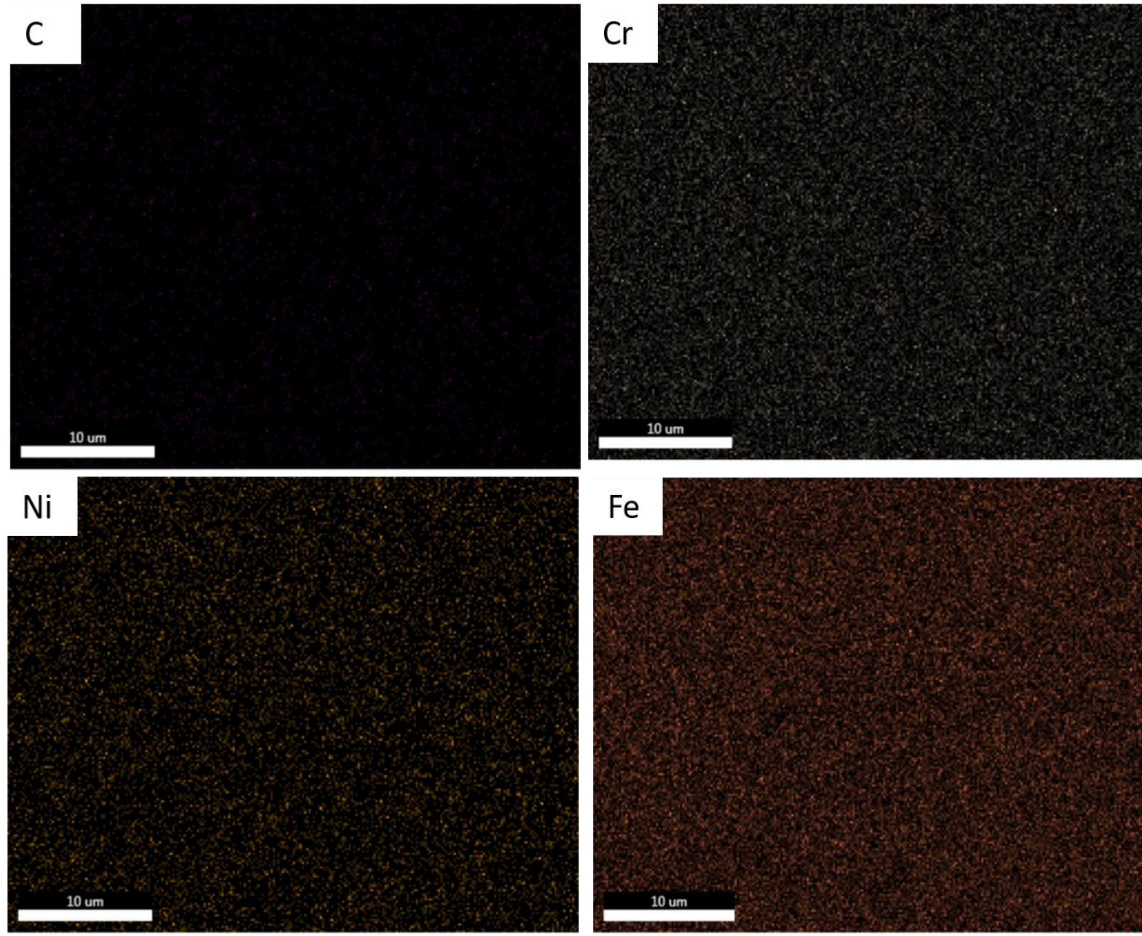


Metallography of P91 and EDX spectrum of carbides after heat treatment

Microstructures of AM-GCTJ

- No Cr depletion was observed along the grain boundary after heat treatment



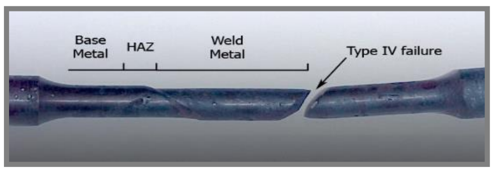


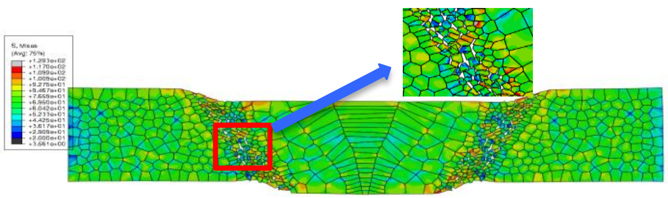
Elements distribution of 304H austenite after heat treatment

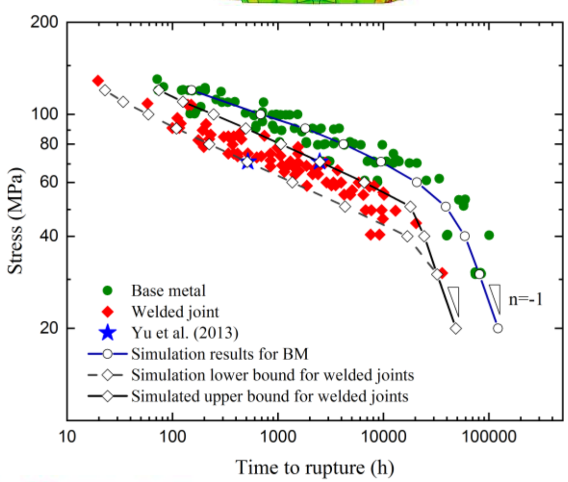
Microstructure-Informed High Temperature Creep Fatigue Damage and Failure Simulations

- Build upon ORNL's Integrated Computational Welding Engineering (ICWE) modeling framework
  - Extended to Thermal cyclic loading of DMW and Transition Joint

Life prediction of G91 Weld



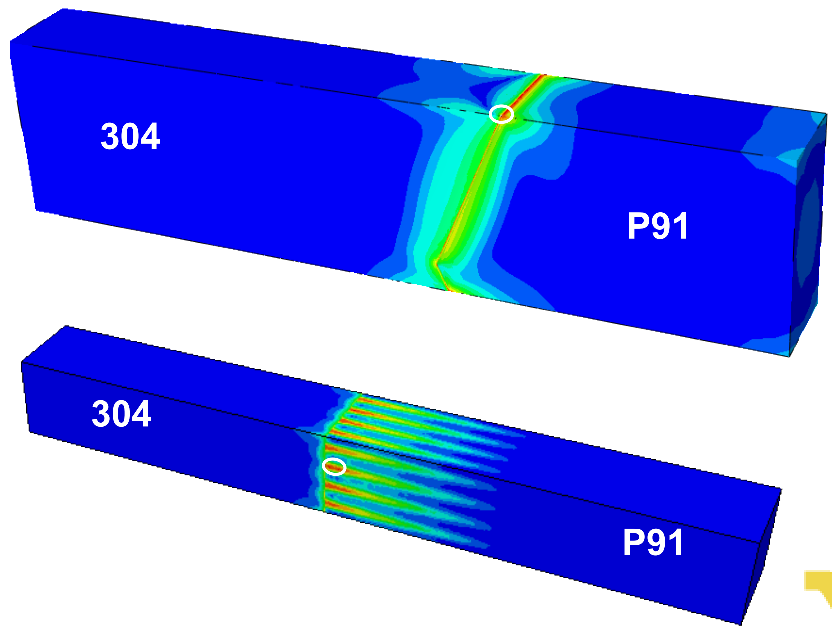




- Thermo-elasto-plasto-creep constitutive model

$$\dot{\boldsymbol{\varepsilon}} = \dot{\boldsymbol{\varepsilon}}^{el} + \dot{\boldsymbol{\varepsilon}}^{thermal} + \dot{\boldsymbol{\varepsilon}}^{pl} + \dot{\boldsymbol{\varepsilon}}^{cr}$$

- Thermal cycling: 2hr heating/2hr holding/2hr cooling
- Note: Model had different details than actual build



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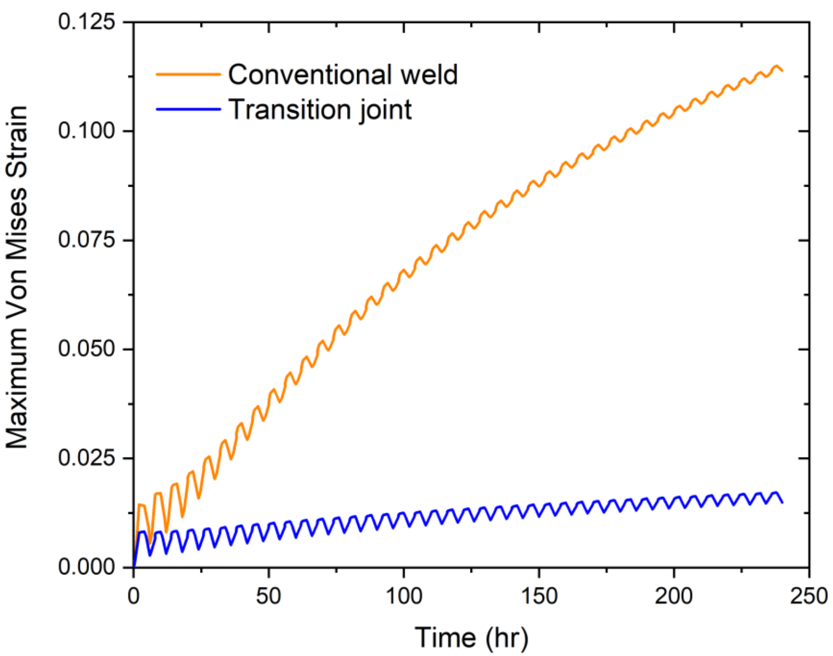
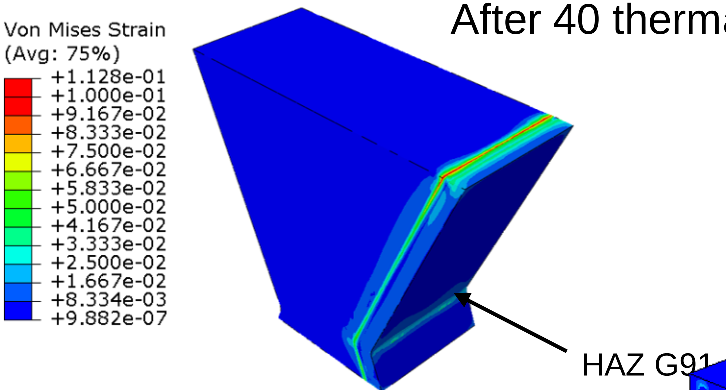
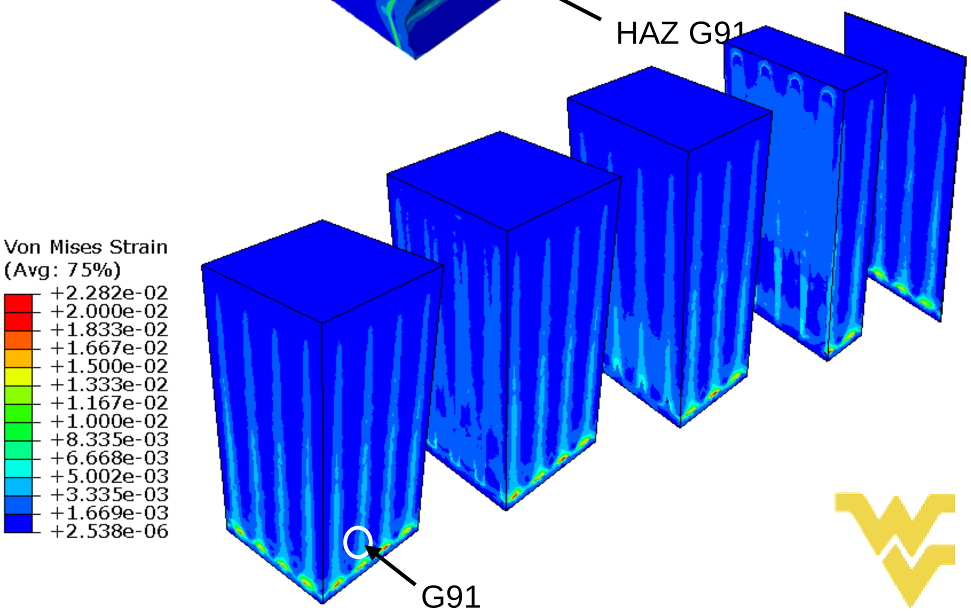
Accumulation of Strain at Critical Locations

- AM-GCTJ significantly reduces the strain accumulation at critical locations from thermal cyclic loading

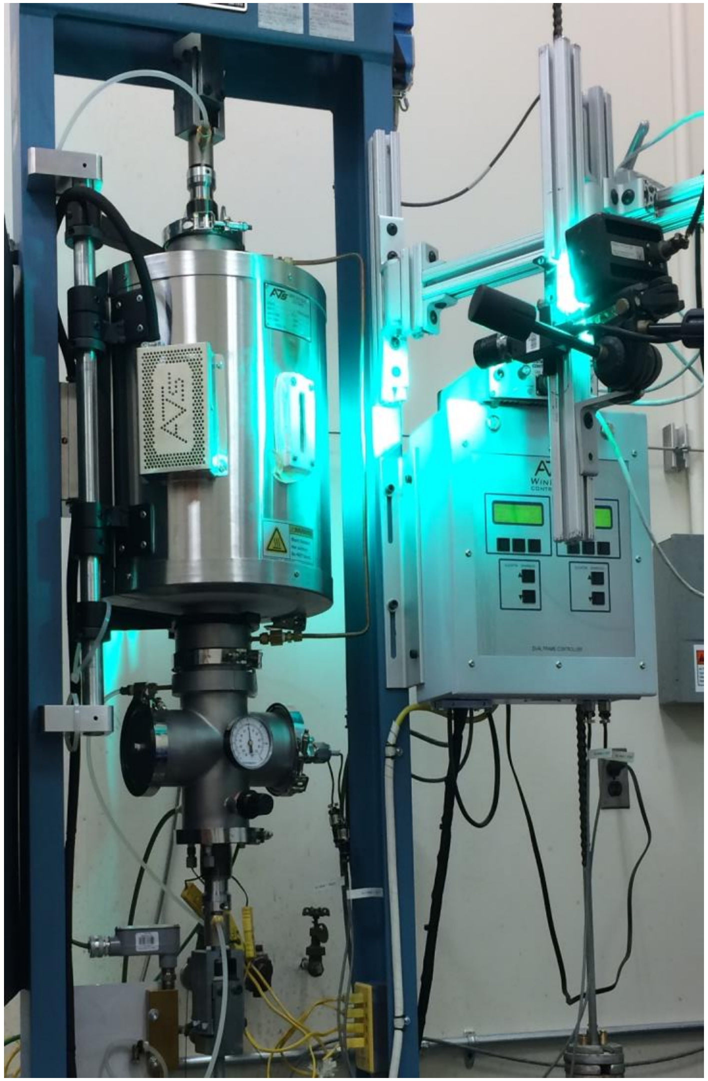


After 40 thermal cycles

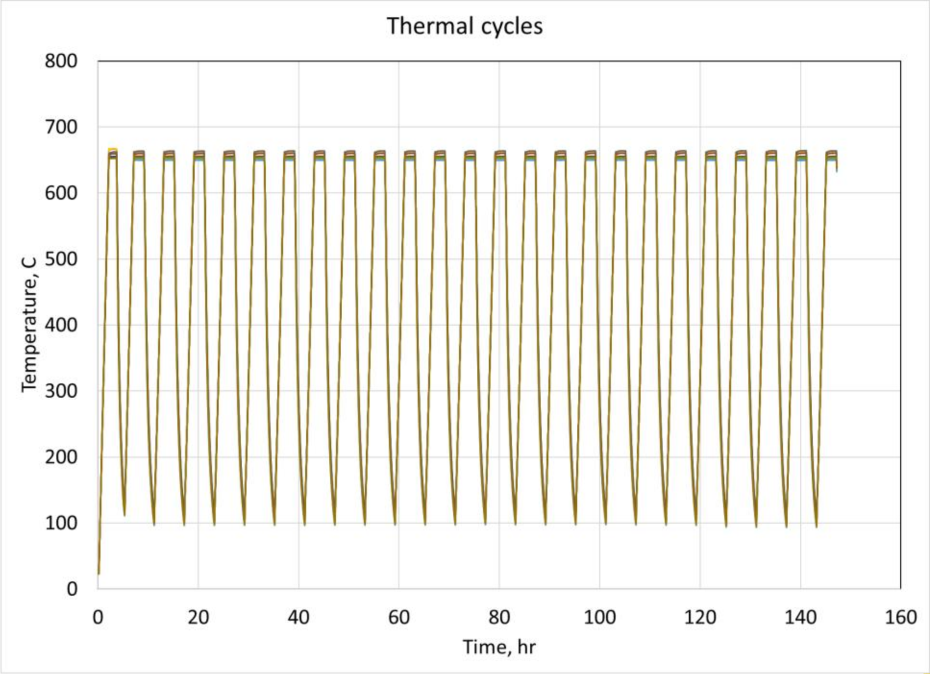




Thermal Cyclic Tests using a Purposely Built in-situ Full-Field Strain Measurement System with HT DIC

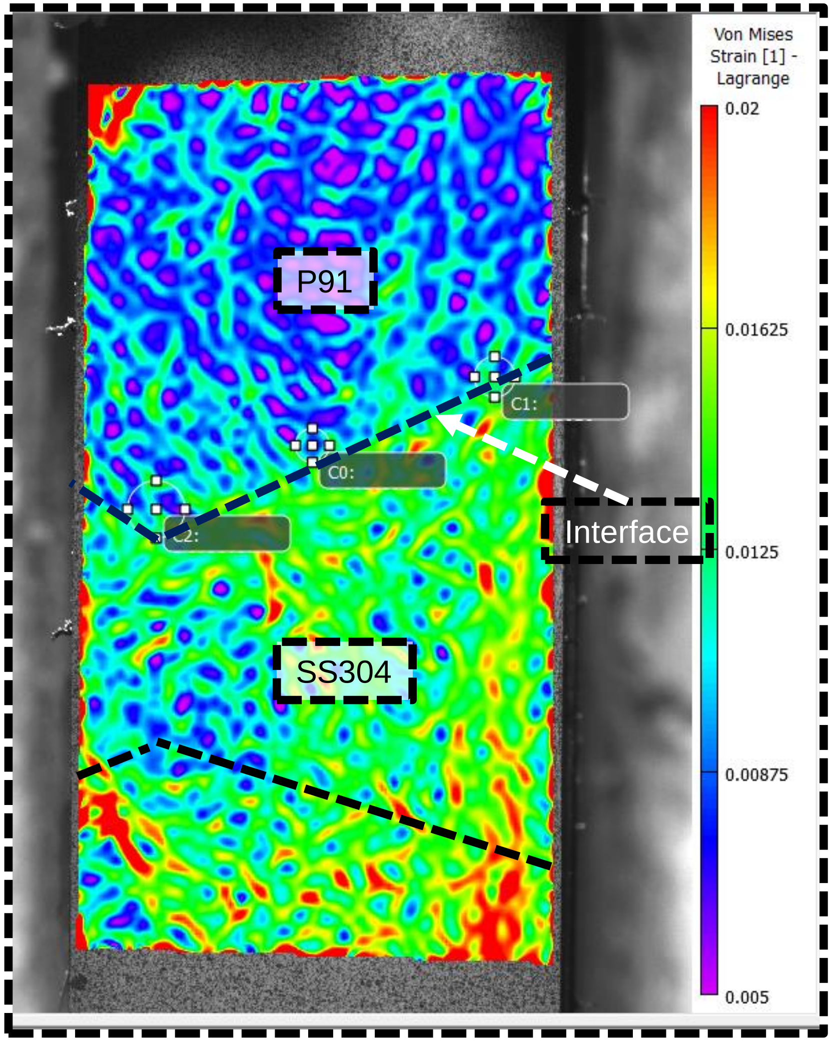


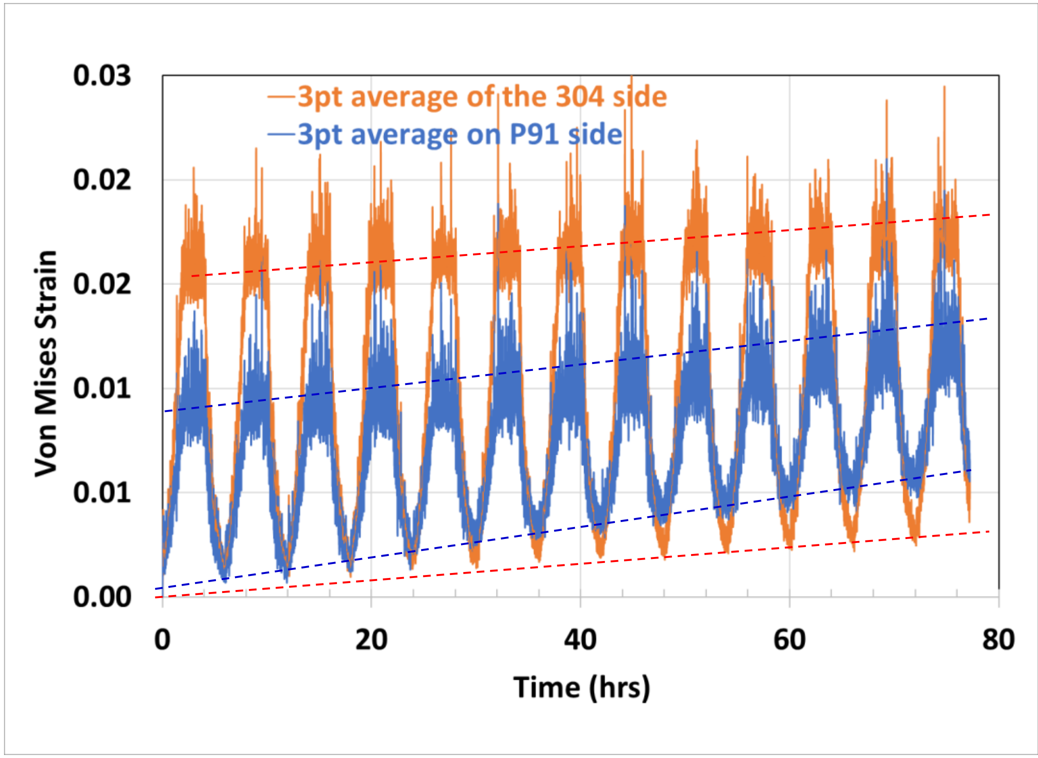
- Thermal cycling:
  - Heating to 650C/2hr
  - Holding at 650C for 2 hrs
  - Cooling to 100C/2hr in furnace
- Specimen size:
  - 4”(L)x1”(W)x0.5”(t)



Strain Map and Evolution during Thermal Cyclic Test (ongoing)

Conventional DM Weld





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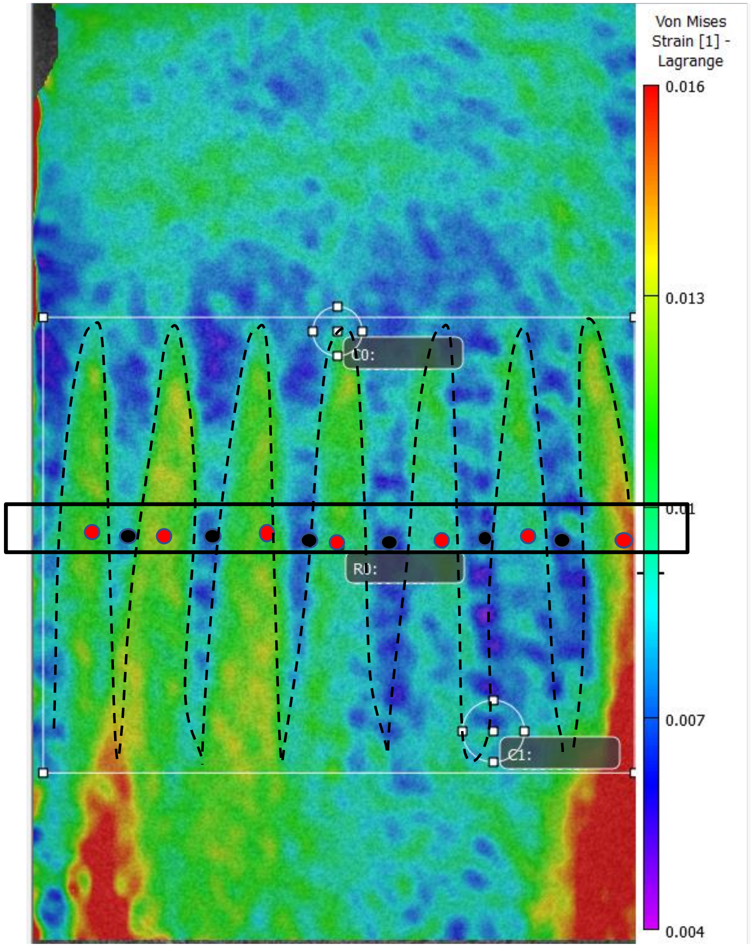
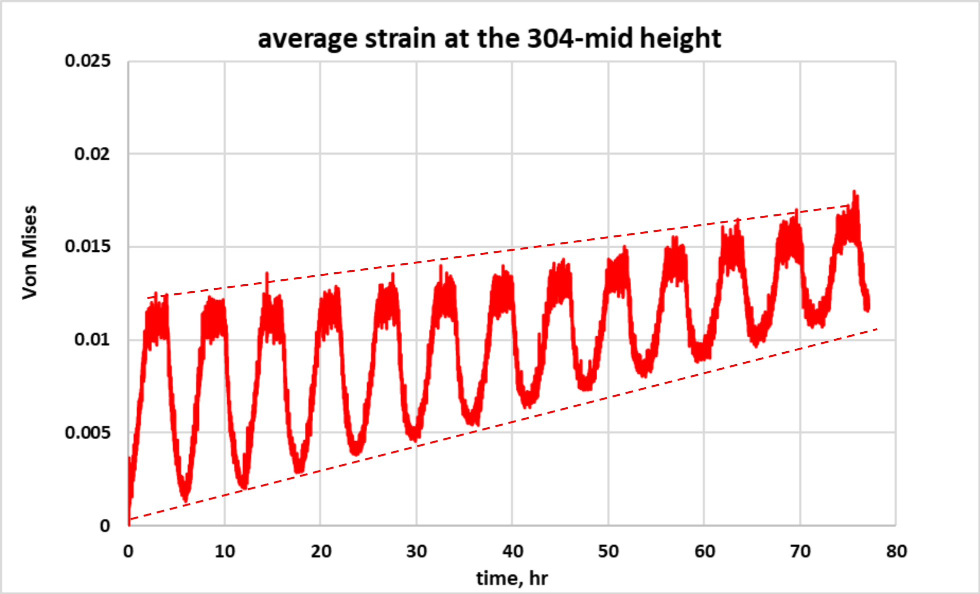
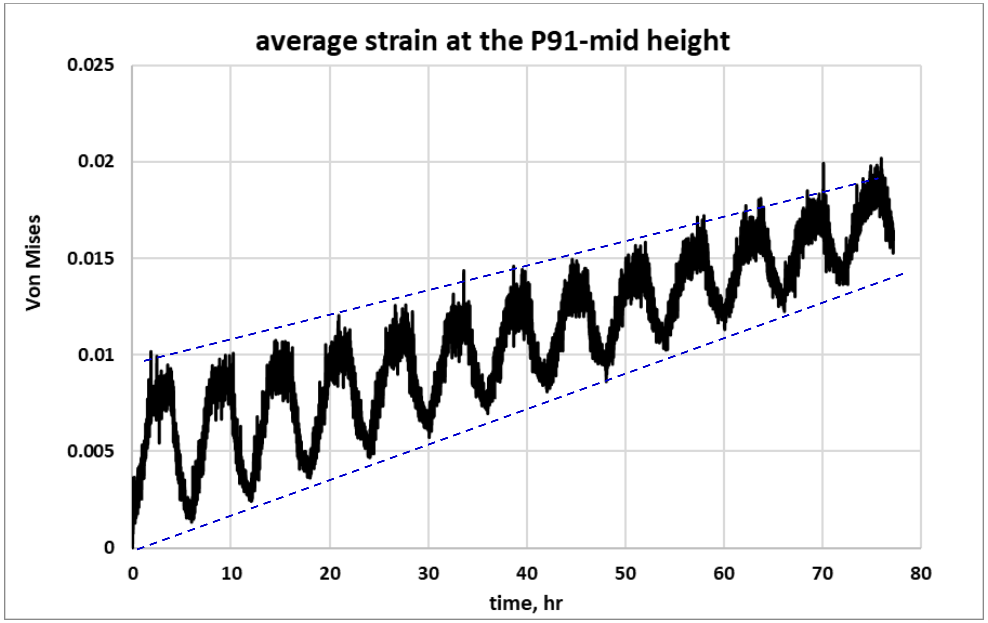
Strain Map and Evolution during Thermal Cyclic Test (ongoing)

AM-GCTJ







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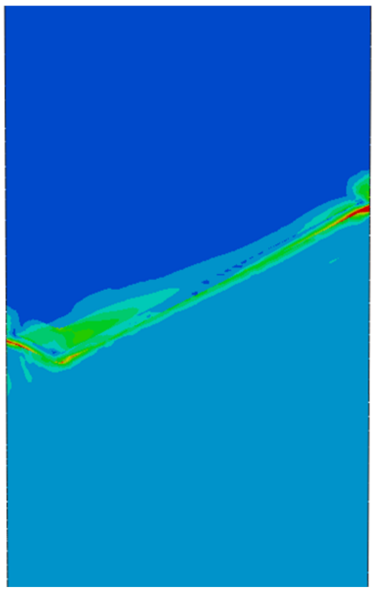
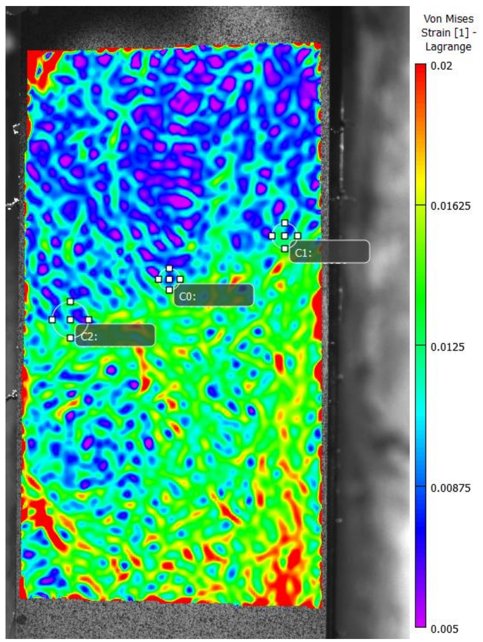
Model Captured Essential Features of Strain Distributions

Conventional DMW

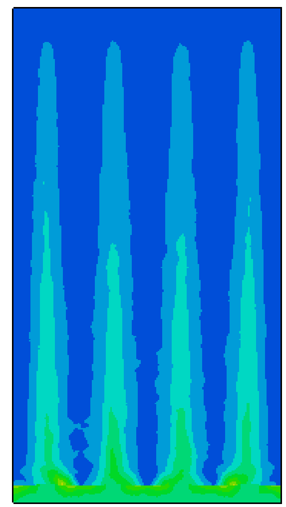


Model

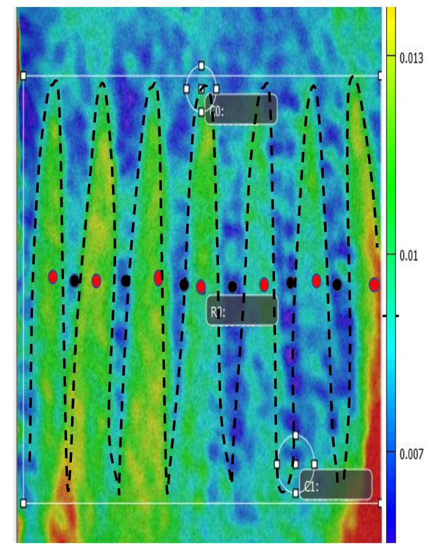


DIC

AM-GCTJ



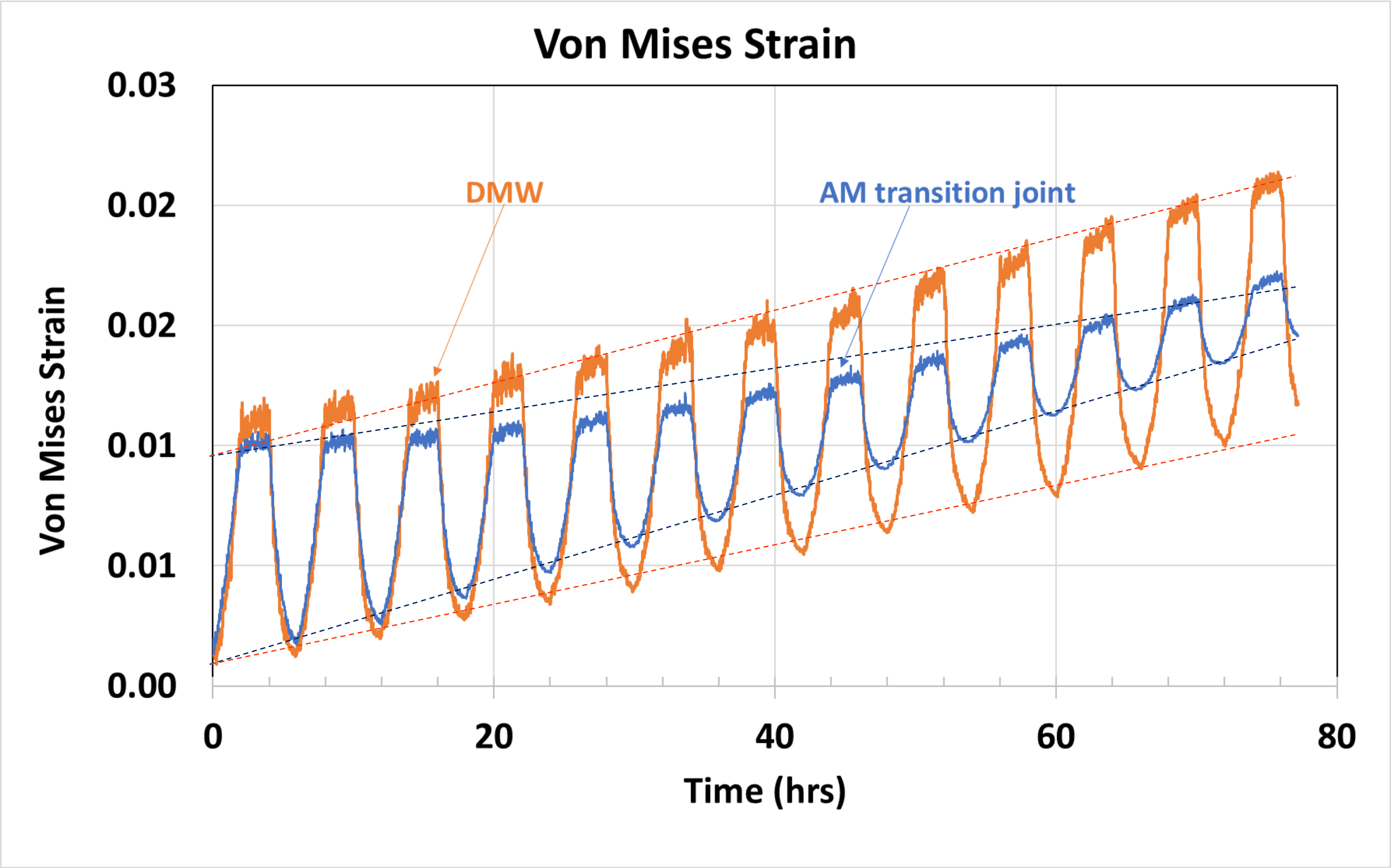
Model



DIC

Strain Evolution during Thermal Cyclic Tests

- Initial observations from in-situ DIC measurement:
  - Considerable reduction of thermal cyclic strain range with AM-GCTJ



AM-GCTJ: averaged over the transition region
Conventional DMW: averaged over P91/SS304 interface region

Summary and Future Work

- We designed and fabricated a new class of AM-GCTJ
  - Avoid unknown & often undesired complex composition in the conventional AM-GTJ
  - Reduce the maximum strain and (can) improve thermal mechanical fatigue life of DMW during cyclic operation of thermal-electric power plants
- Phase I Remaining: Further optimize heat treatment, and characterizations
- Phase II: Detailed TEA; further optimize design and manufacturing; move up both TRL & MRL; start code case; be ready for commercial applications.

Acknowledgements

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- NETL: Briggs White, Michael Fasouletus
- All Collaborators and Team Members